

## METHODOLOGY FOR SUSTAINABILITY ANALYSIS FOR THE ENERGY SECTOR: THE CASE OF LPG AS REPLACEMENT FOR FIREWOOD IN RURAL HOUSEHOLDS IN COLOMBIA

### Metodología para el análisis de la sostenibilidad del sector energético: el caso del GLP como sustituto de leña en los hogares rurales de Colombia

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#### Abstract

In this paper we provided a sustainability analysis for the LPG energy sector in Colombia using different methodologies: analysis of primary and secondary sources of normative documents; programmatic and regulatory framework of LPG; a study on the current tax burden of fuel gas subsidies; scenarios for the expansion of LPG subsidies; a socio-environmental sensitivity analysis; identification of relevant territorial factors to make prioritization recommendations in the replacement of firewood by LPG in specific areas; LPG emissions estimations as a strategy for replacing firewood in rural homes and the analysis of the economic sustainability of the business using different indicators. The research begins with a brief introduction which describe and highlights the importance of analyzing studies of natural gas and LPG in Colombia. The first section briefly exposes the theoretical and conceptual framework that supports the research. The second section presents the methodology used for each of the analysis topics. The third section shows some of the results achieved during the investigation and the main conclusions. Finally, we provide a series of reflections and insights for sustainability research where the dialogue of knowledge and multidisciplinary is encouraged.

**Key words:** *sustainability, energy transition, methodology, energy sector, LPG, firewood, cooking fuel.*

#### Resumen

Presentamos un análisis de sostenibilidad para el sector energético de GLP en Colombia utilizando diferentes metodologías: análisis de fuentes documentales primarias y secundarias de documentos normativos; marco programático y regulatorio del GLP; un estudio sobre la carga tributaria actual de los subsidios al GLP; escenarios para la expansión de los subsidios al GLP; un análisis de sensibilidad socio-ambiental; identificación de factores territoriales relevantes para hacer recomendaciones de priorización en la sustitución de la leña por el GLP en áreas específicas; estimaciones de emisiones de GLP como estrategia para reemplazar la leña en hogares rurales y el análisis de la sostenibilidad económica del negocio utilizando diferentes indicadores. Se presenta una breve introducción en donde se destaca la importancia de este tipo de investigaciones en Colombia. La primera sección resume el marco conceptual que respalda la investigación. La segunda sección presenta la metodología utilizada para cada uno de los temas de análisis. La tercera sección muestra algunos de los resultados logrados durante el desarrollo de la misma. Finalmente, se proporcionan una serie de reflexiones e ideas para la investigación de sostenibilidad fomentando el diálogo del conocimiento y la multidisciplinariedad.

**Palabras clave:** *sostenibilidad, transición energética, metodología, sector energético, GLP, leña, combustible para cocción.*

## 1. INTRODUCTION

Natural Gas and LPG are currently fundamental energy sources for the Colombian energy matrix, therefore researching the sustainability of the processes associated with the exploration, production, distribution, and consumption of gas in the country is essential to generate prospects for regional sustainable development within the general framework of a global energy transition.

Since the 1990s, Colombia began a transformation in the energy matrix as a result of the discovery of mega gas fields in the north of the country. Natural gas was promoted through different public policies that improved the infrastructure and competitiveness for its distribution and commercialization in areas of the national territory [1].

In 1993, before the implementation of the gas massification plans, 30% of households in Colombia used electricity for cooking, 38% used natural gas or LPG, 21% firewood and 11% used other fuels such as kerosene, gasoline or cooking oil. By 2020, 86% of homes use natural gas or LPG, 10% firewood, 3% electricity and other fuels represent 1%.

Natural Gas -GN- is the main fuel for cooking in urban areas given the technical facilities provided by gas connections. 80% of households in the municipal capitals have a connection to Natural Gas and use it as cooking fuel.

In rural areas where there is no possibility of massive connection to gas pipelines, LPG has been positioned as one of the most important cooking fuels. For the year 2020, the Quality-of-Life Survey (ECV) estimated that 21.9% of households in Colombia used LPG as the main fuel for cooking. While in rural areas this percentage was 43.3%, making it for the first time the most used fuel in the rural sector [2].

In addition to the importance of gas for millions of urban and rural homes, in the thermal, industrial, and commercial sector, gas is an essential factor for

productivity. The industrial and thermal sector consumed around 53% of the country's Natural Gas in 2021.

The industrial sector is the main driver of demand in the country and, according to UPME projections, it is expected to continue to be so until 2033, when thermal consumption for electricity generation is expected to grow [3]. Between 2025 and 2030, the UPME has projected an average growth rate of 0.40% for Natural Gas and 2.44% for LPG. In the medium growth scenario, the demand for Natural Gas would reach 1,300 GBTUD per year by 2035, while the demand for LPG would reach 42,000 GBTUD. In this scenario, the deficits between the national supply and the demand for NG can be reached as soon as 2026 if there is no increase in national production. Which could mean the loss of national energy autonomy and put millions of homes at risk due to price increases subject to international volatility.

### *1.1. Sustainability and energy transition: analysis reference frameworks*

Sustainability is a concept that emerged as a social, economic, and environmental ideal in the late 1970s [4]. The concept became relevant worldwide after the publication of the Brundtland Report, also known as the Report: "Our Common Future" where an explicit definition of sustainable development was given. Henceforth, the term ceases to simply belong to the academic community and the history of ecological thought and begins to form part of public opinion and common sense. However, sustainability and sustainable development remain disputed concepts and their precise meaning depends on different attitudes and ideologies towards social, environmental, and economic problems [5][6].

Despite this, we can speak of a hard core of sustainability and sustainable development in two key aspects 1) The notion of complexity and interdependence of real systems, which implies the interrelation between the economic, social, and environmental dimensions and 2) The notion of inter and intra generational justice, which means the search for conditions so that future societies can develop [7]. These coordinates of sustainability and sustainable

development imply seeking development models that allow future generations their own development, understanding the complexity of the relationships between the economic, social, and ecological dimensions.

The definition of sustainability that guided the research was based on the idea of The Natural Step Foundation called "System Conditions" [5][8] which establishes that the principles of sustainability will aim at:

- Eliminate the human contribution to the systematic increase in the concentrations of substances from the lithosphere in the ecosphere.
- Eliminate the human contribution in the systematic increase of substances produced by society in the ecosphere.
- Eliminate the human contribution to the systematic degradation of the physical conditions of the biosphere.
- Eliminate the human contribution in conditions that systematically impede the ability of people to meet their needs.

This definition provides the framework for a more precise understanding of sustainability as it focuses on reducing the damage caused by human activity. In this way, sustainability is understood as the ability for human activities to be channeled into the principles.

One of the main implications of this definition is that it allows us to understand sustainability as a long-term process in which it is possible to take different paths that lead towards these principles. This long-term process is particularly important when analyzing the sustainability of energy systems. Given that the energy transition is one of the central concerns of the organizations, institutions and actors that promote the different visions of sustainability, understanding the transition as a long-term process with different possibilities of action within a framework of complex relationships between the social, economic and environmental dimension is essential to avoid establishing roadmaps that are impossible to meet with absolute criteria that may even be detrimental to the principles of sustainability themselves.

One of its main components of this long-term path of sustainability is the so-called energy transition. Given that one of the main motivations within the sustainable development and sustainability agenda is the reduction of GHG due to adverse climatic effects on different human activities. The change in the energy matrix towards a diversified matrix with less participation of fossil fuels is one of the priorities worldwide [9][10].

The current energy transition is part of a history of technological transformations that have occurred since the 18th century that have been linked to changes in the use of primary energy. Robert Ayres has theorized about three great technological transformations and a fourth transformation still underway that have produced the great changes within modern societies, allowing continued economic expansion [11].

In a similar scheme but more focused on the proper energetic transitions and not only energetic-technical ones, but it is also possible to establish the existence of three transitions. The first coincides with the transition from the use of traditional biomass fuels to coal, the second with the emergence of oil and its derivatives, the third with the positioning of natural gas and the fourth with the entry of renewable energy sources [12]. The technological transformation that is currently taking place is facing a series of important challenges, particularly in the energy transition towards renewable energies, that is, the transition from a fossil civilization [13] to a renewable energy civilization. Table 1 summarizes the main challenges facing the energy transition on the global stage.

In the research we have consider these challenges and what they represent for a global south country like Colombia. As said before, the energy transition as a long-term process towards sustainability means that the public policy must adapt to the conditions given in a certain space and time, because of that, we concluded that the use of LPG as a replace for woodfire in rural areas was worth considering as a possible alternative for reaching SDG goals particularly SDG number 7: Affordable and clean energy.

**Table 1.** Challenges of the energy transition

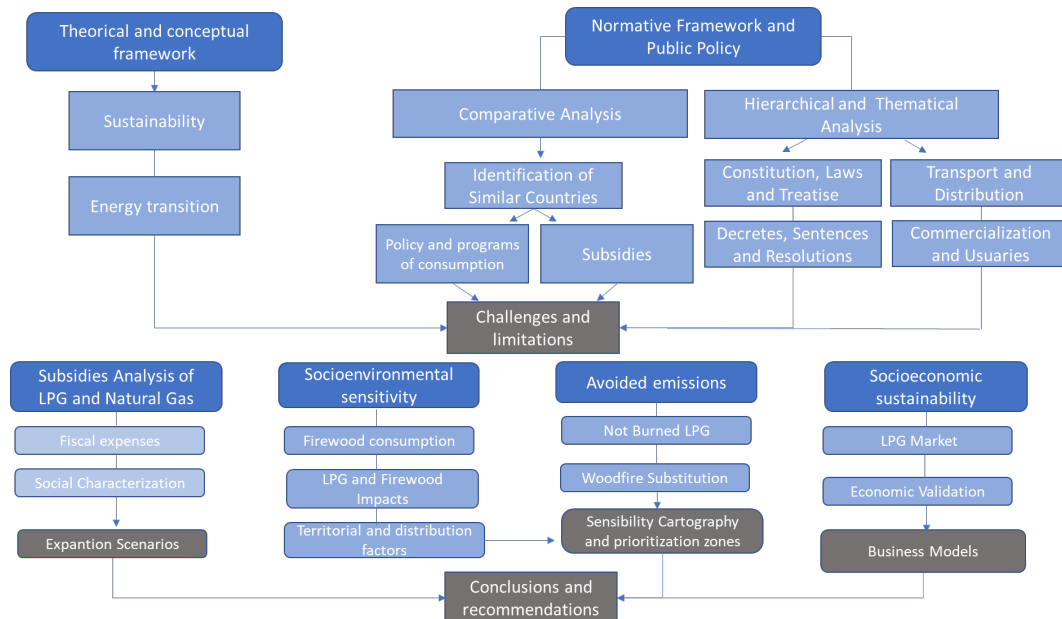
Challenge	Implications
Political	International cooperation and coordinate action to mitigate climate change in a short period of time [9] [14][15].
Geopolitical	Weak incentives to achieve transitions, creation of new interest for key raw materials [14].
Economic	Possible burst of the “carbon bubble” as investments shift from fossil fuels to other sectors [16].
Inequality Gap	Technological backwardness in global south countries [17].
Infrastructure, capacity, and logistics	Difficulty for the replacement of fossil fuels in key areas

## 2. MATERIALS AND METHODS

The research project “GEOLOGICAL HABITAT, PROSPECTIVITY, SOCIO-ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY OF WET GAS (LPG) IN COLOMBIA AS A FUEL OF ENERGY TRANSITION” had the

objective of carrying out a geological study within the commercial hydrocarbon production basins to establish a series of scenarios prospects for wet gas (LPG) reserves in Colombia, all articulated to a perspective of environmental, social, and economic sustainability and sustainable development. To develop the research on the social, environmental, and economic sustainability of LPG as a transition fuel, we started from the analysis of the theoretical and conceptual framework that focused on the study of the concept of sustainability and energy transition and how the five lines of research were articulated with these concepts. At the same time, progress was made in the necessary analyzes of the five lines of research for which the study of the regulatory framework and public policy in each of the themes was essential.

The analysis of the regulatory and public policy framework allowed feedback on the research lines (Subsidies, Socio-environmental Sensitivity, Avoided Emissions and Socioeconomic Sustainability) to the extent that it allowed the identification of challenges and limitations within public policy at the national level and the challenges demanded by the changes and the roadmaps proposed at the international level by different organizations.



**Figure 1.** Methodology used in this research. **Source:** authors, 2023.

### *2.1. Methodology for the analysis of Subsidies*

For the analysis of NG natural gas and LPG wet gas subsidies, the expenses in Natural Gas and LPG subsidies in the period 2017-2021 were evaluated. This evaluation was accompanied by a socioeconomic characterization of the users of Natural Gas and LPG, to try to determine if the subsidies are being efficient in their allocation. For this, the following variables within households were considered:

- Household has a network connection to natural gas
- Household uses LPG as the main fuel for cooking
- Household uses firewood as the main fuel for cooking
- Household stratum
- Total household income
- Household per-capita income

The determination of the LPG subsidy expansion scenarios considered the vital minimum determined by the UPME, as well as empirical consumption averages in households measured in surveys. For the determination of the price of LPG, prices were taken as a reference.

### *2.2. Methodology for the analysis of socio-environmental sensitivity*

The analysis of socio-environmental sensitivity to the use of firewood for cooking food in homes, is carried out to prioritize those territories where the substitution of this fuel for a more efficient, less polluting, and harmful to the health of the population becomes more urgent and therefore, guarantee greater access to clean energy.

To carry out this analysis, we started from the analysis of the quantitative and spatial consumption of firewood in the country, the impacts that the use of this energy source generates and the identification of those that are most relevant. For each of the most relevant socio-environmental impacts, indicators are identified that reflect territorial sensitivity to said impact.

The sensitivity indicator corresponds to a condition of the territory, the population or the dwelling that has the potential to cause or maximize unwanted effects of cooking with firewood. These correspond to territorial

factors. Then, a weighted aggregation of the territorial factors is carried out, with which the integrated sensitivity index is obtained, which, as well as the individual indicators, is specialized in maps.

Finally, we proceeded to identify the territorial factors for the distribution of LPG in cylinders, which were crossed with the integrated sensitivity map to obtain as a result the map of priority areas for a program to replace firewood with LPG.

### *2.3. Methodology for the analysis of emissions*

The calculation of avoided emissions consists of two components:

- Calculation of possible emissions avoided using the portion of wet gas that is currently burned in the country's production fields.
- Calculation of possible emissions avoided by the eventual replacement of firewood that is currently used in homes for cooking food with LPG.

To perform the first calculation, the gas information associated with the country's production fields was processed, those with gas composition information were filtered, and finally the portion corresponding to wet gas of the gas that is currently flared was obtained. Taking the volume of the portion of wet gas that is burned, the calculation of the emissions that it generates was made, and therefore those that could be avoided if it were not burned in the Teas.

For the second calculation, we start from the volume of firewood used for cooking in rural homes, the emissions are calculated and compared with the emissions generated by LPG that would have been required to do the same job. The difference between the emissions of firewood and LPG emissions correspond to the possible emissions avoided with the substitution of firewood.

### *2.4. Methodology for the analysis of economic sustainability*

For the development of this economic sustainability analysis, the LPG market in the country was reviewed,

which includes the offer from the point of view of gas availability based on the statistics of production data published by the National Hydrocarbons Agency (ANH). The data used corresponds to the gross production of the fields.

The demand study was carried out by sector, which has grown in recent years driven by the policies of mass use of LPG (for example, in the rural sector due to programs to replace firewood with this fuel).

After reviewing the business models that are used in the industry from different points of view, they were basically summarized in two: a first model in which the field operator is in charge of the processing and commercialization of gas products, and a second model in which the operator delivers the gas to a third party to take charge of its processing and marketing. Both have advantages and disadvantages.

For the economic analysis of the LPG business in the country, the existing regulation on the subject was reviewed and that focuses on the mass use of it, grants incentives and subsidies, which has a direct impact on demand. The country's offer was reviewed, based on the associated gas production data at the country level and an economic valuation exercise was carried out for a selected area.

### 3. RESULTS AND DISCUSSION

In this section we illustrate the results of the investigation by showing some graphic examples and some of the general conclusions of the research. It should be mentioned that these examples are purely illustrative of the results of the work and do not represent the bulk of the work carried out during the investigation.

#### 3.1. Graphic results

The Table 2 summarizes the results of allowances. The final product was a series of expansion scenarios for the LPG subsidy in the country.

The Figure 2 constitutes the result of applying the sensitivity equation through an image rasterization process. The map represents the territorial sensitivity to the cutting of firewood given the possible effects that this activity could generate on the environment and the population.

The map shows that the most sensitive areas are concentrated in Córdoba, Antioquia, Nariño, Cauca, Tolima, Boyacá, Norte de Santander and with medium sensitivity, important areas are observed in the Amazon, Orinoquía, Chocó, the Caribbean region and Bolívar, among others.

The following equations represent the calculation of the CO<sub>2</sub> emissions that would be avoided if LPG was not burned in the production fields. According to the calculations around 21 million tons of CO<sub>2</sub> could be avoided. Other results, concerning public policy, normative frames and socioeconomic sustainability were discussed and presented in the research but are not presented here due to the length it will demand.

$$\text{Total LPG}_q = 921.34 \text{ mpc}$$

$$1pc = 0.0283$$

$$921,340,000 \text{ pc} = 26,089,400 \text{ mc}$$

$$1mc \text{ of LPG} = 264,172 \text{ gallons}$$

$$\text{LPG}_q = 26,089,400 \text{ mc} \times 264,172 \frac{\text{gallons}}{\text{mc}}$$

$$\text{LPG}_q = 6,892,101,818.2 \text{ gallons}$$

$$\text{CO}_2 \text{ emissions} = 21,029,181,067.0816 \text{ Kg CO}_2$$

$$\text{CO}_2 \text{ emissions} = 21 \text{ million tons CO}_2$$

An important output of the research was to formulate a series of conclusions regarding the production, consumption and distribution of LPG in Colombia associated with the replacement of firewood as cooking fuel in rural areas. Here we present some of the most important conclusions derived from the investigation.

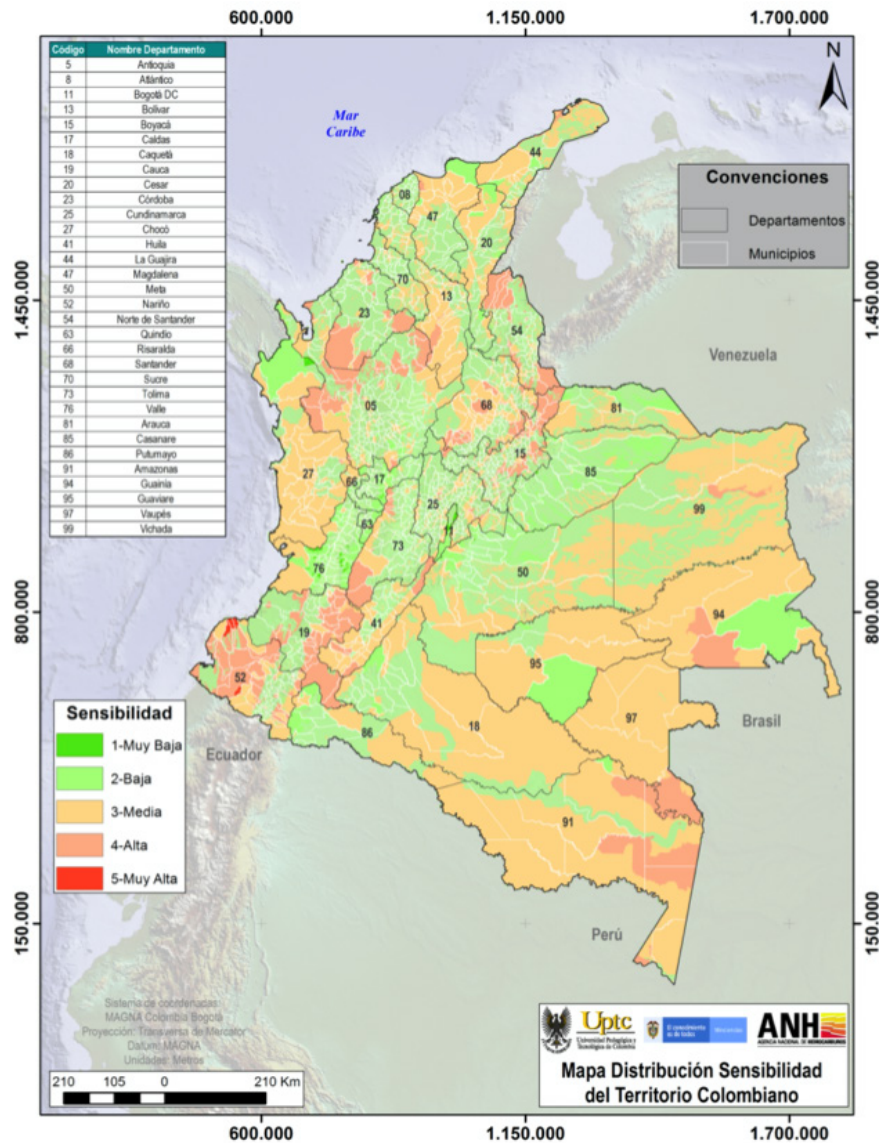


Figure 2. Socio-environmental sensitivity results. Source: authors, 2023.

Table 2. Results of allowances

Variables	Q1	Q2	Total
Households	792,000	790,000	1,582,000
Kg allowances per month	6	4.8	
Average price LPG (Kg)	3,304	3,304	
Cost	15,702,718,861	12,530,452,425	28,233,171,286

#### 4. CONCLUSIONS

Within the international regulatory framework to which Colombia belongs, there are different incentives for the increase in the consumption, production, and distribution of LPG. Among them, the reduction of GHG emissions, the increase in energy efficiency, the reduction of deforestation, among others.

Within the national regulatory and programmatic framework, there are incentives to increase the consumption, production, and distribution of LPG. In accordance with laws, government plans, CONPES, resolutions and decrees.

LPG is an excellent fuel for the energy transition as it contributes to the three fundamental pillars of public policy in the energy sector:

- Improves accessibility to energy, through the substitution of firewood for cooking in rural homes.
- It contributes to the reduction of greenhouse gases, since it generates 25% less CO<sub>2</sub> than firewood, 24% less than coal, 8.5% less than diesel and 3.1% less than gasoline.
- Contributes to the improvement of energy efficiency, especially in the residential sector, with the replacement of a fuel with very low efficiency such as firewood (3-15%) by LPG, which has efficiencies between 35-50%.

The growing demand for LPG in the country in recent years is largely due to the mass use programs promoted by the national government, such as the firewood substitution plan and subsidies granted by the government for sectors of the population with lower income.

Even though LPG was defined as an essential public service in Law 142 of 1994, this is the only public service that does not have a subsidy that covers the most vulnerable population in the entire country. The subsidies established for LPG are focused on a defined group of municipalities.

The design of subsidies for fuel gas in Colombia has disproportionately benefited Natural Gas to the detriment of LPG, which has meant that the poorest households in

the country do not have access to clean and efficient fuels for cooking.

The current allocation by strata of the Natural Gas subsidy is inefficient to the extent that it allocates resources equally to households with very different incomes, since the allocation method is stratification. By establishing alternative forms of subsidy targeting, it would be possible to release resources for the LPG subsidy.

The use of firewood for cooking in homes generates multiple socio-environmental impacts, among which the most important are:

- The loss of vegetation cover and biomass and therefore the affectation of biodiversity.
- The increase in the demand for women's time for unpaid work and leisure, and the decrease in the time available to children for study and leisure.
- The impact on health from the smoke from burning firewood, mainly due to particulate matter, which mainly generates respiratory problems, especially in women, but also in children.

The environmental sensitivity indicators for the three most important impacts of the use of firewood for cooking in homes are:

- The presence of sensitive ecosystems, associated with the affectation of ecosystems.
- The multidimensional poverty index, associated with the increase in the demand for time in unpaid work for adults and children.
- Cooking food in a closed room, associated with health impairments from wood smoke.

The socio-environmental sensitivity analysis for the country yields approximately 1 million hectares in high sensitivity, around 5 million in medium sensitivity and a little less than 5 million in low sensitivity. The most sensitive areas are concentrated in Córdoba, Antioquia, Nariño, Cauca, Tolima, Boyacá, and Norte de Santander, and with medium sensitivity, important areas are observed in the Amazon, Orinoquía, Chocó, the Caribbean region, and Bolívar, among others.



Two fundamental distribution factors for LPG cylinders are accessibility and population density. In terms of accessibility, it is considered that the areas that belong to the SIN and the mixed areas are relatively easily accessible, so a program to replace firewood with LPG can be implemented. From the population point of view, the criterion included in UPME (2022) of serving municipalities that have a rural population greater than the urban one is included.

Regarding the LPG that is currently burned in production fields, the largest volumes correspond to the Caño Limón, Chichimene and Pauto Sur fields and in terms of basins, those with the highest volumes of LPG burned in total correspond to the Middle Magdalena Valley and Eastern Plains followed by the Upper Magdalena Valley and the Piedmont Zone. In Catatumbo there are no reports of gas flaring and in the Lower Magdalena Valley the amount of gas flaring is very low.

The energy generated by the fraction of humid gas that is currently burned in the country's production fields amounts to 604 PJ, which corresponds to 5.8 times the energy generated by firewood for cooking food in homes per year in Colombia.

The presence of gas in the production of hydrocarbons has begun to stop being seen as a problem, and now it is a business opportunity that is evaluated within the technical, economic and commercial parameters (demand), which allow determining the feasibility of treating it as a product that generates value for the company.

There are several examples in the country that prove that the gas business is viable. Companies that previously burned or reinjected the associated gas in the production of crude have decided to send it to a gas plant to obtain an economic benefit from it through the different products that can be extracted. Each case is different, and it is a matter of detailed analysis of the possibilities that the business individually can promise.

## **5. REFLECTIONS ON SUSTAINABILITY RESEARCH**

Finally, we propose a series of reflections for research on sustainability linked to energy resources within the framework of the global energy transition.

In the first place, sustainability research must necessarily be multidisciplinary, it must combine diverse methodologies and it must present quantitative and qualitative analyzes with the aim of accounting for complex systems and the interrelationships between society, economy, culture, and the environment. The integration of knowledge also implies an epistemological position where there is no epistemic privilege or a privileged inclination towards the "hard sciences", quantitative methods and numerical results. Human and social sciences, qualitative methods and conceptual results should be considered as equally valid results. Linked to this, it is necessary to recognize that sustainability research lacks an absolute foundation and that the different visions of the concept of sustainability and its interpretations in the short, medium, and long term influence the studies, methodologies, and results. Another of the key elements that we have identified in the research is the need for a long-term vision to propose pragmatic solutions within the different social, economic, technological, logistical constraints, etc. This is of particular importance within the energy transition, since it is a civilizational change of great relevance, comparable to previous major transformations such as the industrial revolution.

In the methodological aspect, the research found it vitally important to clearly establish the regulatory framework (national and international) that includes aspects of international politics, national legality, and the interaction between these components. It is within the regulatory framework where sustainability research can support clear objectives and public policy recommendations.

The use of social cartography is another of the key elements for the methodology, to the extent that it allows the results of an investigation to be clearly communicated to different actors and decision makers. Finally, the

proposal of a series of public policy recommendations so that decision makers and society in general can participate in the debate is an essential element in research on sustainability within the energy sector.

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